Accelerating structures: 3 TeV and 500 GeV CLIC designs, HOM damping and technology alternatives

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Outline

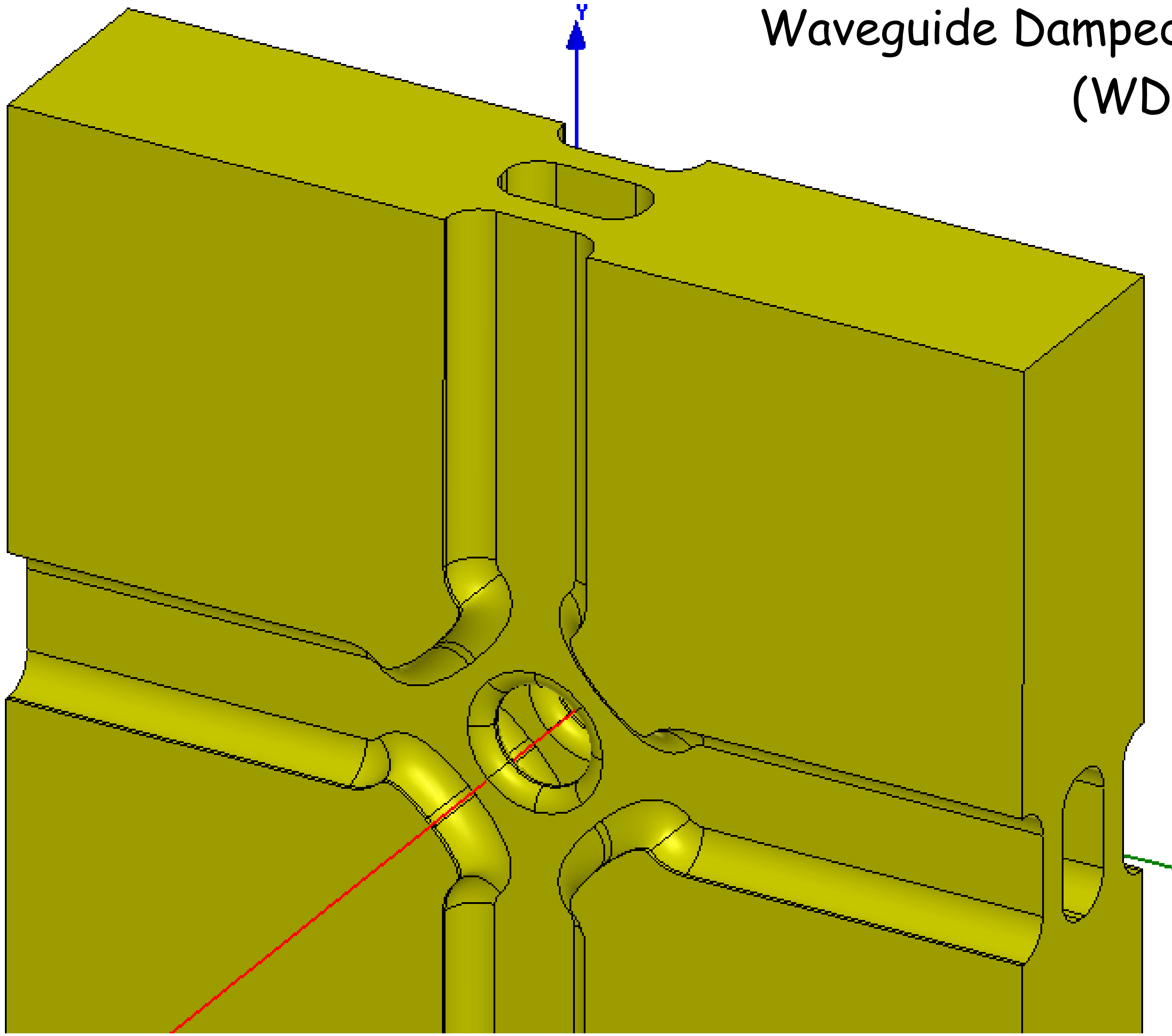
- 3 TeV CLIC accelerating structure design
- 500 GeV CLIC accelerating structure design
- Alternative HOM damping
  - Choke mode damping
  - Damped Detuned Structure
- Technology alternatives
  - Quadrant
  - Brazed Disk
    - Single rounded cell
    - Double rounded cell

30′

- Coupler alternatives
  - Mode launcher coupler
  - Electric coupler
  - Magnetic coupler with damping
- Ridged waveguide damping for lower pulse surface heating temperature rise

3 TeV CLIC accelerating structure design

WDS cell geometry



Waveguide Damped Structure (WDS) 2 cells

- Minimize E-field
- Minimize H-field
- Provide good HOM damping
- Provide good vacuum pumping

Optimization constraints

Beam dynamics (BD) constraints based on the simulation of the main linac, BDS and beam-beam collision at the IP:

- **N – bunch population** depends on $\langle a \rangle/\lambda$, $\Delta a/\langle a \rangle$, f and $\langle E_a \rangle$ because of **short-range wakes**
- **N_s – bunch separation** depends on the **long-range dipole wake** and is determined by the condition:

$$W_{t,2} \cdot N / E_a = 10\ \mathrm{V/pC/mm/m} \cdot 4\mathrm{x}10^9 / 150\ \mathrm{MV/m}$$

RF breakdown and pulsed surface heating (rf) constraints:

- $\Delta T^{max}(H_{surf}^{max}, t_p) < 56$ K
- $E_{surf}^{max} < 260$ MV/m
- $P_{in}/C_{in} \cdot (t_p^{P})^{1/3} = 18\ \mathrm{MW \cdot ns^{1/3}/mm}$

Optimizing Figure of Merit

Luminosity per linac input power:

$$\frac{L}{P_l} = \frac{L_{b\times} N_b f_{rep}}{\dfrac{eE_{cm} N N_b f_{rep}}{\eta}} = \frac{1}{eE_{cm}} \bullet \frac{L_{b\times}}{N}\eta$$

Collision energy is constant

Figure of Merit (FoM = $\eta L_{bx}/N$)
in [a.u.] = [1e34/bx/m²•%/1e9]

Total cost model

Total cost = Investment cost + Electricity cost for 10 years

$$C_t = C_i + C_e$$

$$C_i = \mathrm{Excel}\{f_r; E_p; t_p; E_a; L_s; f; \Delta\varphi\}$$

Repetition frequency;

Pulse energy;

Pulse length;

Accelerating gradient;

Structure length (couplers included);

Operating frequency;

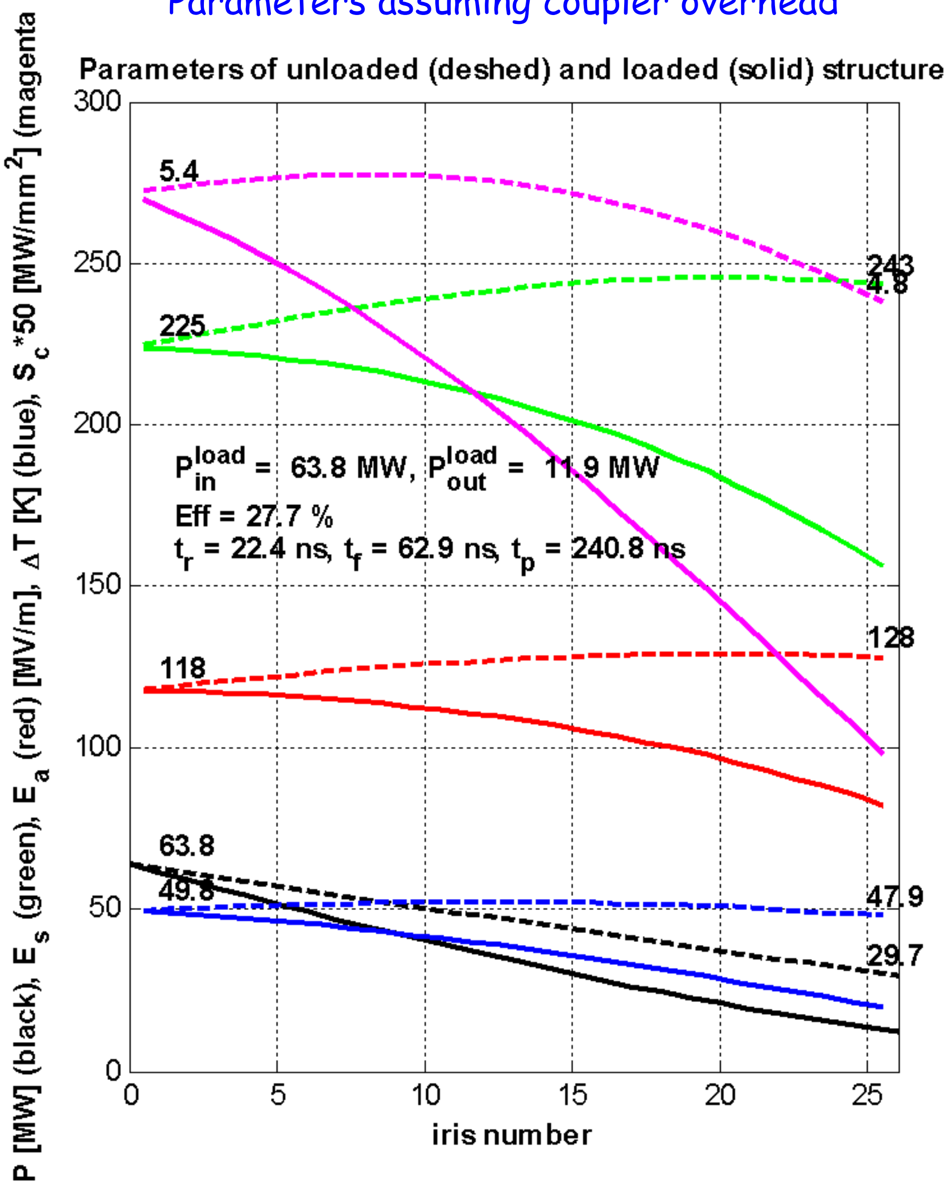
rf phase advance per cell

$$C_e = (0.032 + 2.4/FoM)$$

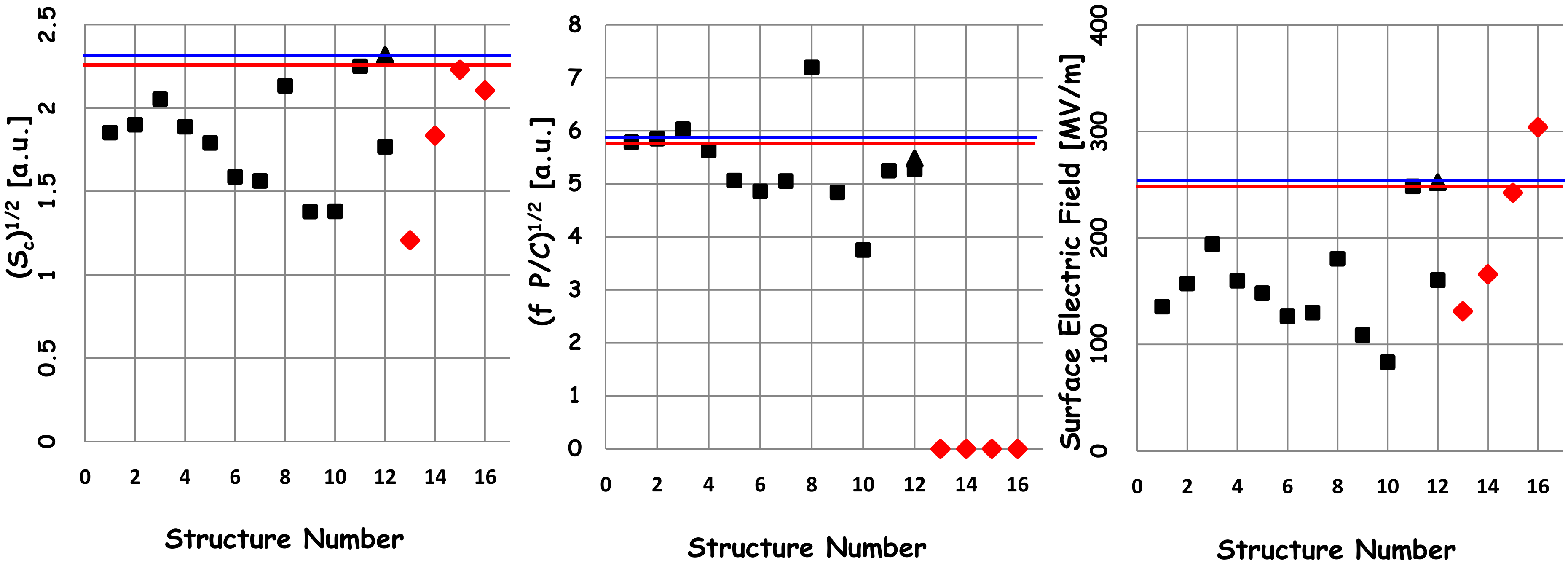
Parameters of 3TeV structure CLIC_G

Structure	CLIC_G
Frequency: f [GHz]	12
Average iris radius/wavelength: $<a>/\lambda$	0.11
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00
Group velocity: $v_g^{(1,2)}/c$ [%]	1.66, 0.83
N. of reg. cells, str. length: N_c, l [mm]	24, 229
Bunch separation: N_s [rf cycles]	6
Luminosity per bunch X-ing: L_b [m^{-2}]	1.22 10^{34}
Bunch population: N	3.72 10^9
Number of bunches in a train: N_b	312
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4
Pulse length: τ_p [ns]	240.8
Input power: P_{in} [MW]	63.8
$P_{in}/C t_p^{1/3}$ [MW/mm ns$^{1/3}$]	18
Max. surface field: E_{surf}^{max} [MV/m]	245
Max. temperature rise: ΔT^{max} [K]	53
Efficiency: η [%]	27.7
Figure of merit: $\eta L_b / N$ [a.u.]	9.1

Parameters assuming coupler overhead



CLIC_G versus X-band measurement data

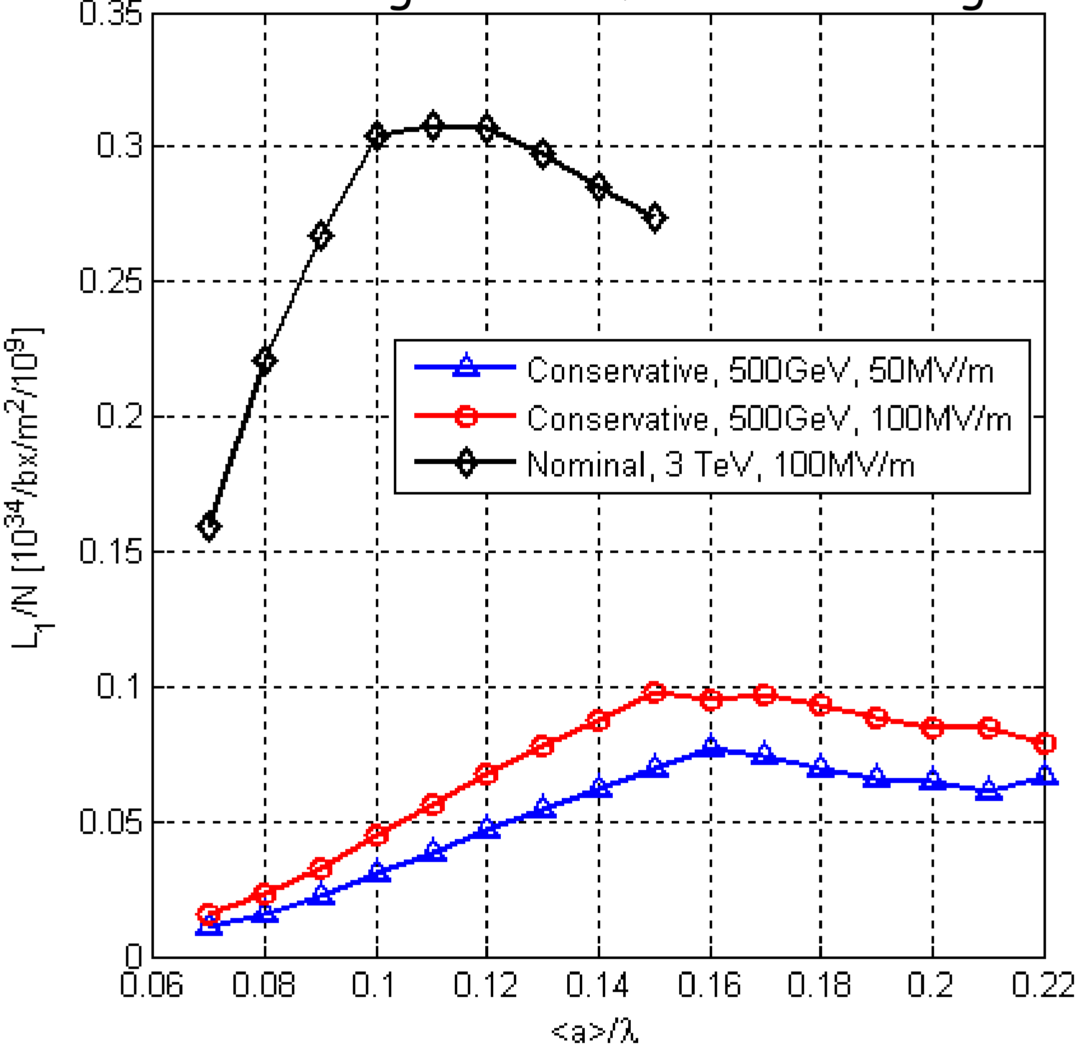


Constraints @ {200ns, BDR=10^{-6} bpp/m} ~ {180ns, BDR=3×10^{-7} bpp/m}

500 GeV CLIC accelerating structure design

Beam dynamics constraints at 500GeV and conservative emittance

Short range wake limits bunch charge



Nominal parameters

$\varepsilon_{x,y}$ = 660nm, 20nm

$\beta_{x,y}$ = 4mm, 0.09mm

Conservative parameters

$\varepsilon_{x,y}$ = 3μm, 40nm

$\beta_{x,y}$ = 8mm, 0.1mm

Long range wake amplitude on the second bunch limits the bunch spacing:

$W_t^{(2)} * N / \langle Ea \rangle$

<

20 V/pC/m/mm * 4x10^9 / 150 MV/m

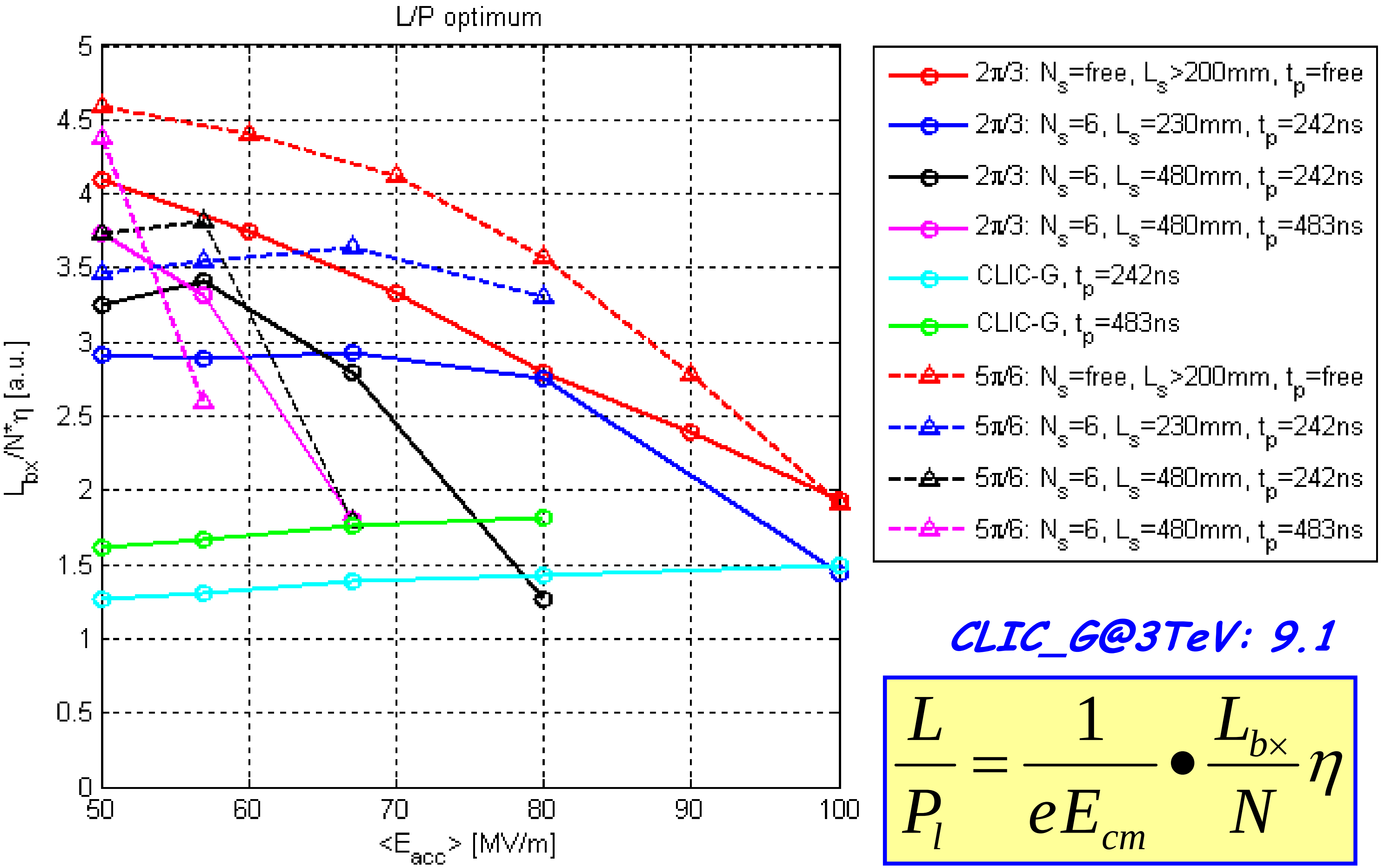
10 V/pC/m/mm has been used for 3TeV

Other constraints

- RF constraints remains the same as for 3TeV:
  - $P/C*t_p^{1/3} < 18$ Wu(MW/mm*ns$^{1/3}$)
  - $E_s^{max} < 260$ MV/m
  - $\Delta T^{max} < 56$ K
  - RF phase advance per cell: 120 or 150 degree
- No 3TeV constraints:
  - Structure length L_s more than 200 mm;
  - Pulse length t_p is free
  - Bunch spacing N_s is free
- 3TeV constraints $N_s = 6$:

1. L_s = 230 mm; t_p = 242 ns
2. L_s = 480 mm; t_p = 242 ns
3. L_s = 480 mm; t_p = 483 ns

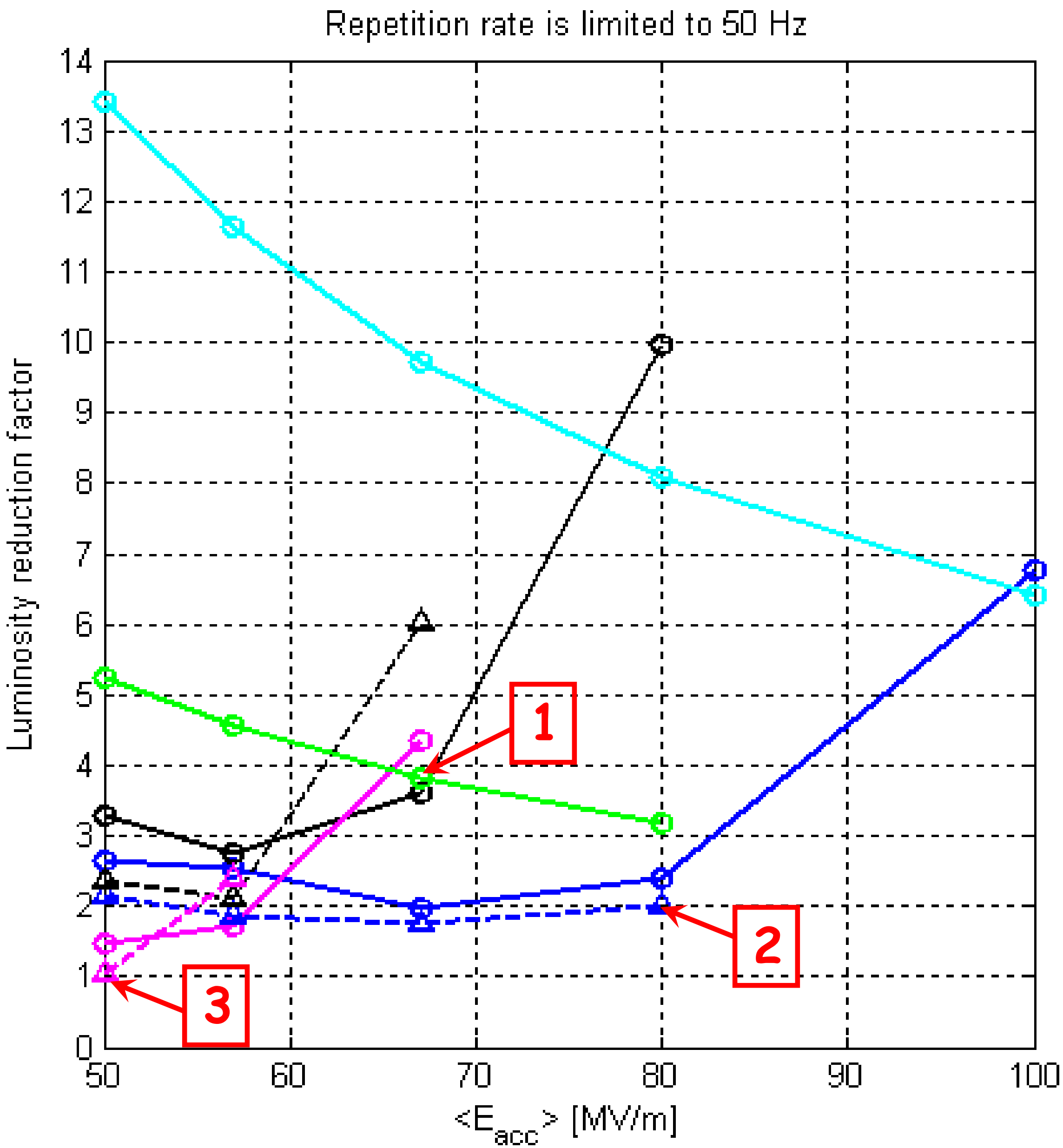
Figure of Merit

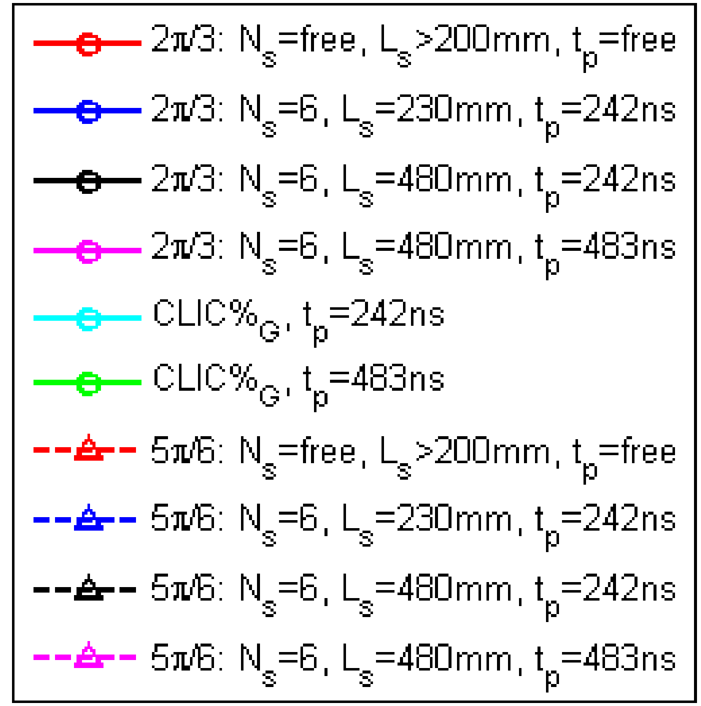


CLIC_G@3TeV: 9.1

$$\frac{L}{P_l} = \frac{1}{eE_{cm}} \bullet \frac{L_{b\times}}{N}\eta$$

If repetition rate is limited to 50 Hz





Case 2 has been chosen:

- As close as possible to 100 MV/m
- Cost considerations which were not included in the optimization
- Beam current in injectors is only ~2 times higher than for 3 TeV
- RF constraints for PETS are the lowest

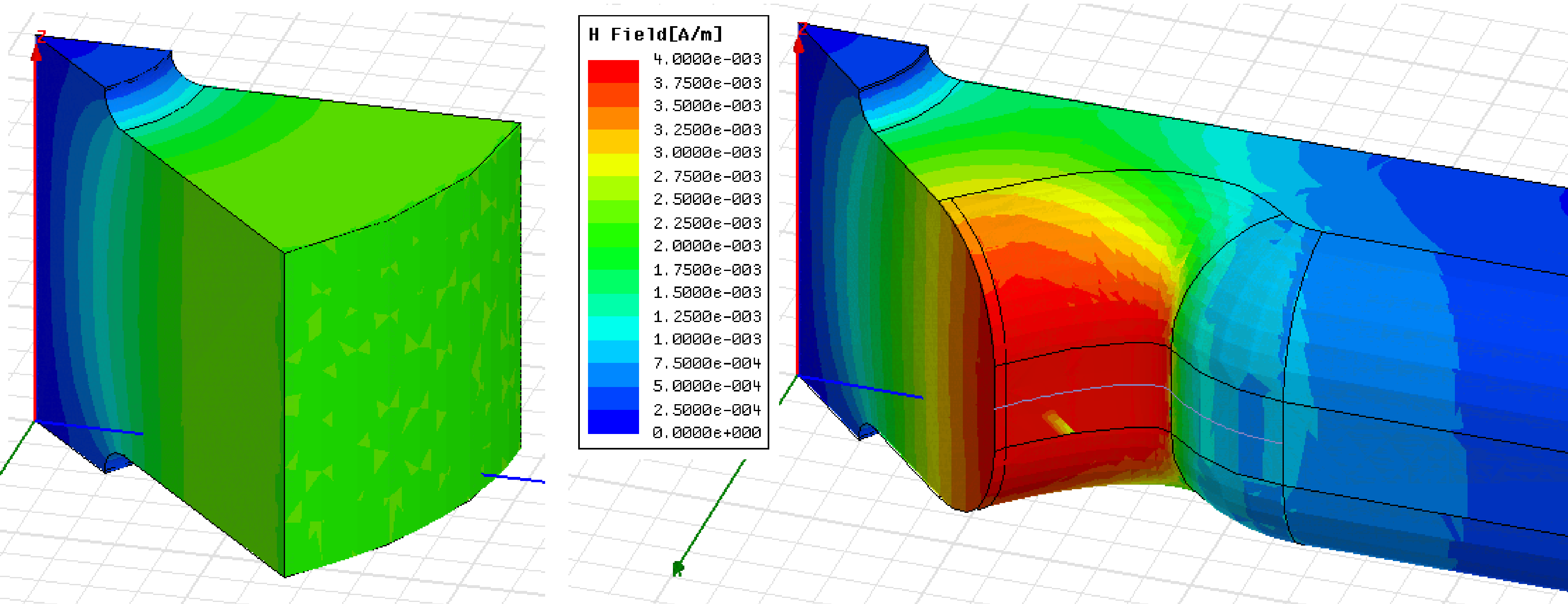
Parameters of the structures

Case	3TeV nominal	500GeV conservative
Structure	CLIC_G	CLIC_502
Average accelerating gradient: $<E_a>$ [MV/m]	100	80
rf phase advance: $\Delta\varphi$[º]	120	150
Average iris radius/wavelength: $<a>/\lambda$	0.11	0.145
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35	3.97, 3.28
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00	2.08, 1.67
Group velocity: $v_g^{(1,2)}/c$ [%]	1.66, 0.83	1.88, 1.13
N. of reg. cells, str. length: N_c, l [mm]	24, 229	19, 229
Bunch separation: N_s [rf cycles]	6	6
Luminosity per bunch X-ing: L_b [m^{-2}]	1.22 10^{34}	0.57 10^{34}
Bunch population: N	3.72 10^9	6.8 10^9
Number of bunches in a train: N_b	312	354
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4	50.3, 15.3
Pulse length: τ_p [ns]	240.8	242.1
Input power: P_{in} [MW]	63.8	74.2
$P_{in}/Ct^P{}_p{}^{1/3}$[MW/mm ns$^{1/3}$]	18	17
Max. surface field: E_{surf}^{max} [MV/m]	245	250
Max. temperature rise: ΔT^{max} [K]	53	56
Efficiency: η [%]	27.7	39.6
Figure of merit: ηL_b /N [a.u.]	9.1	3.3

Alternative HOM damping

- Choke mode cavity
- Damped Detuned Structure

Magnetic field enhancement in WDS



NDS WDS

The Choke mode cavity

Shintake, 1992

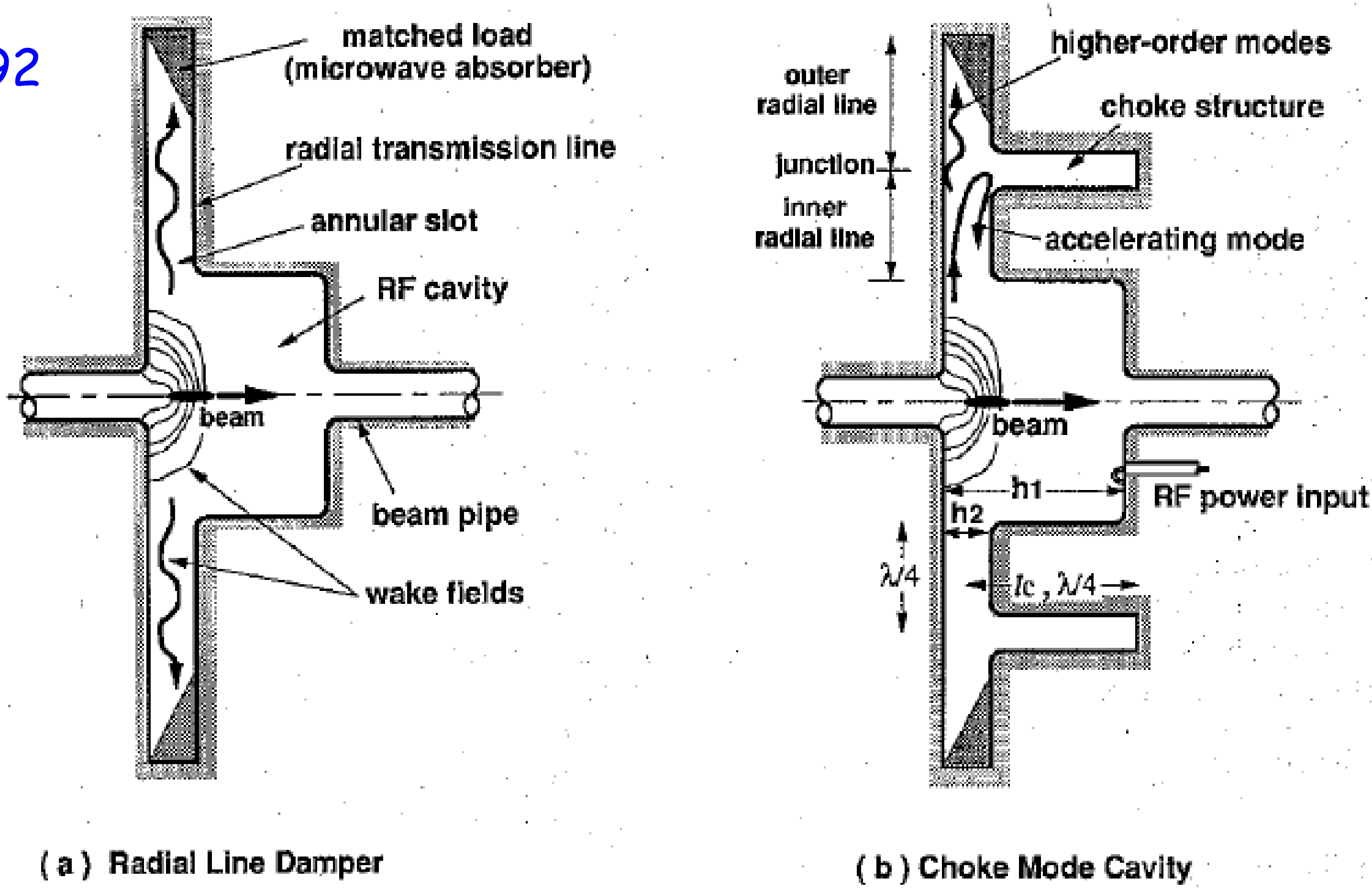
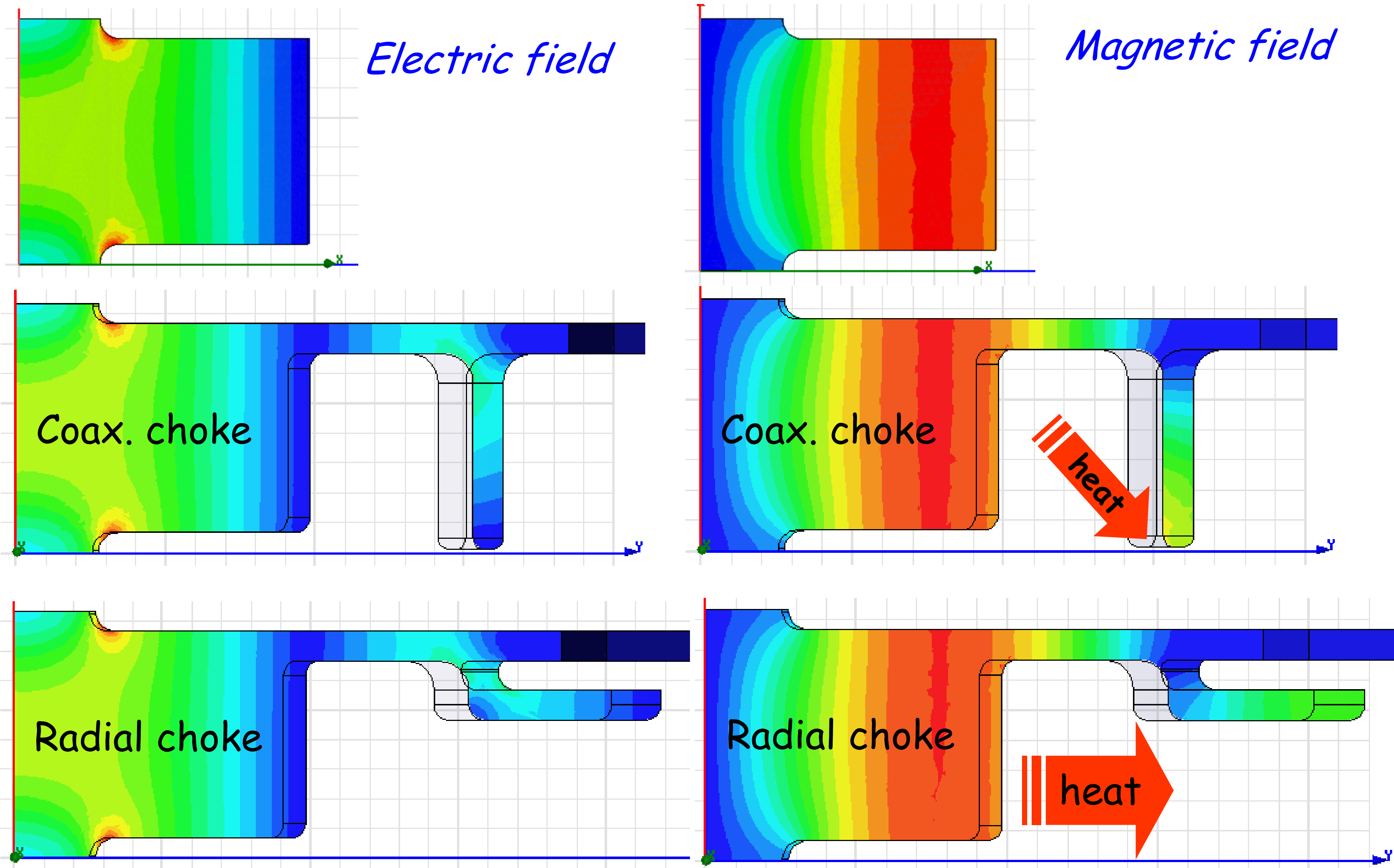


Fig. 1. Conceptual illustrations of (a) a radial line damper and (b) the choke mode cavity.

L 1567

Radial choke for 2π/3 cells



Alternative Wakefield Suppression

- *Alternate method entails heavy detuning and moderate damping of a series of interleaved structures (known as CLIC_DDS). This is a similar technique to that experimentally verified and successful employed for the NLC/GLC program.*
- *Integration of Task 9.2 within NC WP 9 -anticipate test of CLIC_DDS on modules*
- *Potential benefits include, reduced pulse temperature heating, ability to optimally locate loads, built-in beam and structure diagnostic (provides cell to cell alignment) via HOM radiation. Provides a fall-back solution too!*
- *Initial studies encouraging. However, the challenge remains to achieve adequate damping at 0.5 ns intra-bunch spacing*

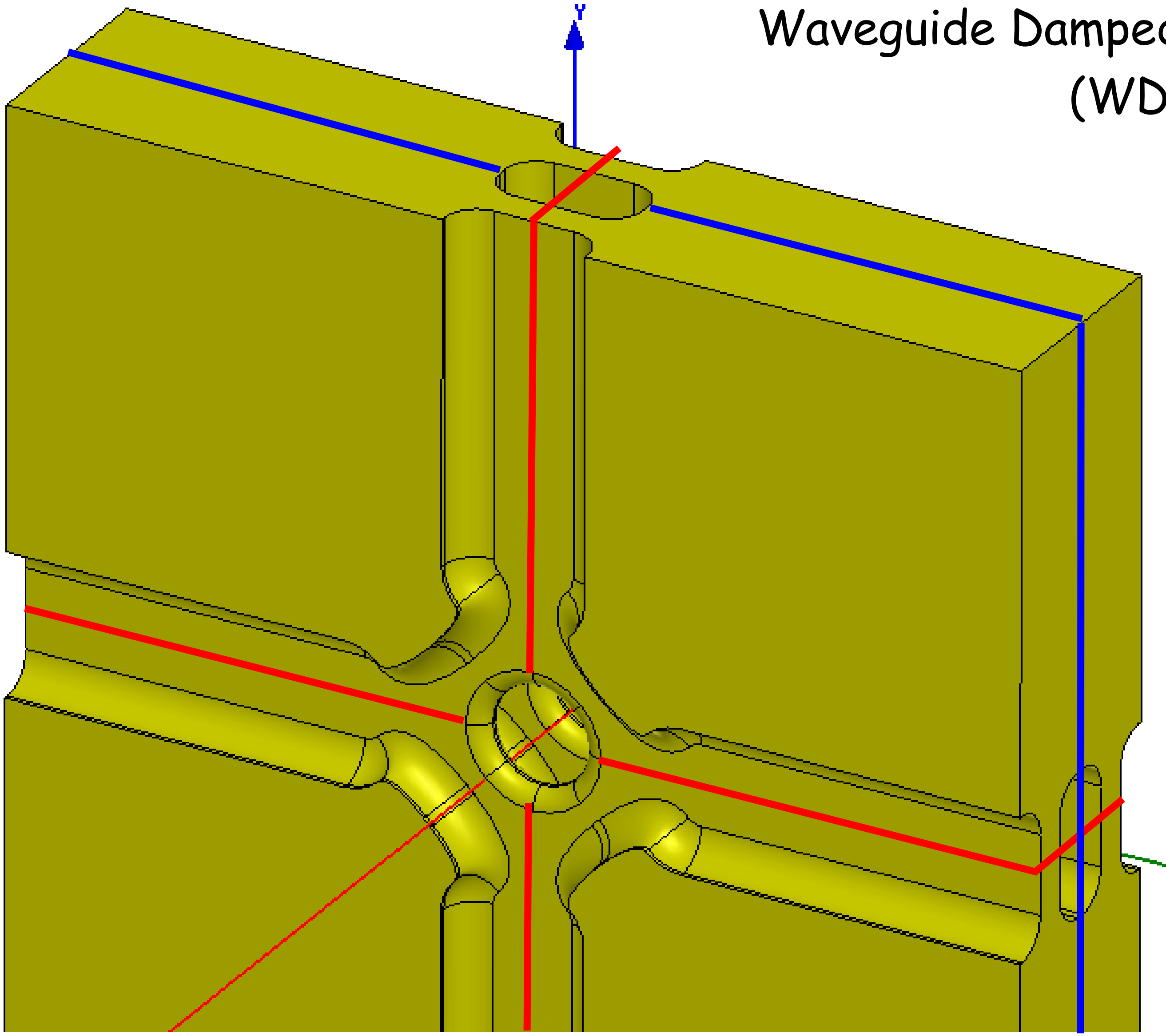
Roger M. Jones, Vasim F. Khan

Technology alternatives

- Quadrant – set a side for the moment
- Brazed Disks
  - Single rounded cell
  - Double rounded cell

WDS cell geometry

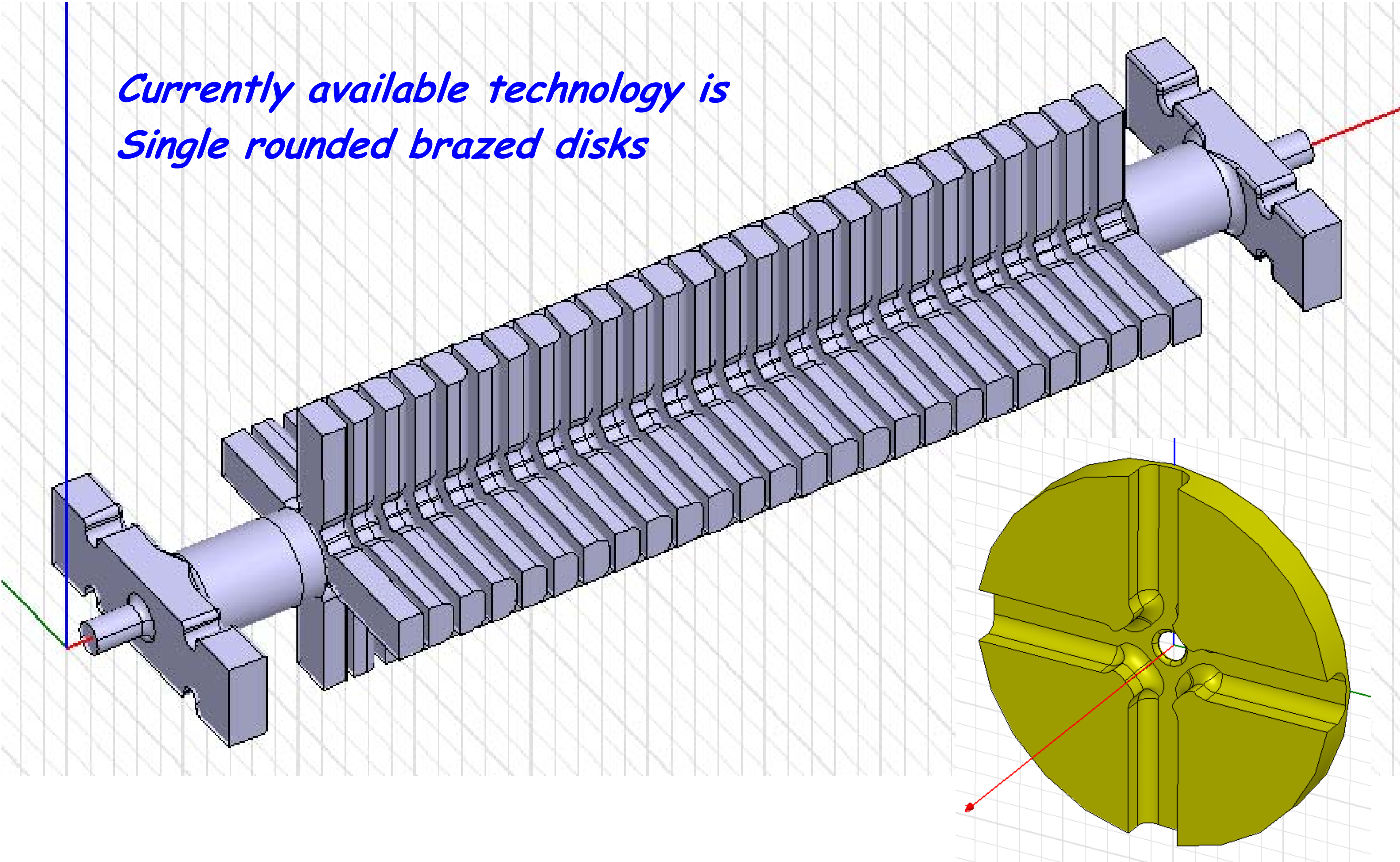
Waveguide Damped Structure (WDS) 2 cells



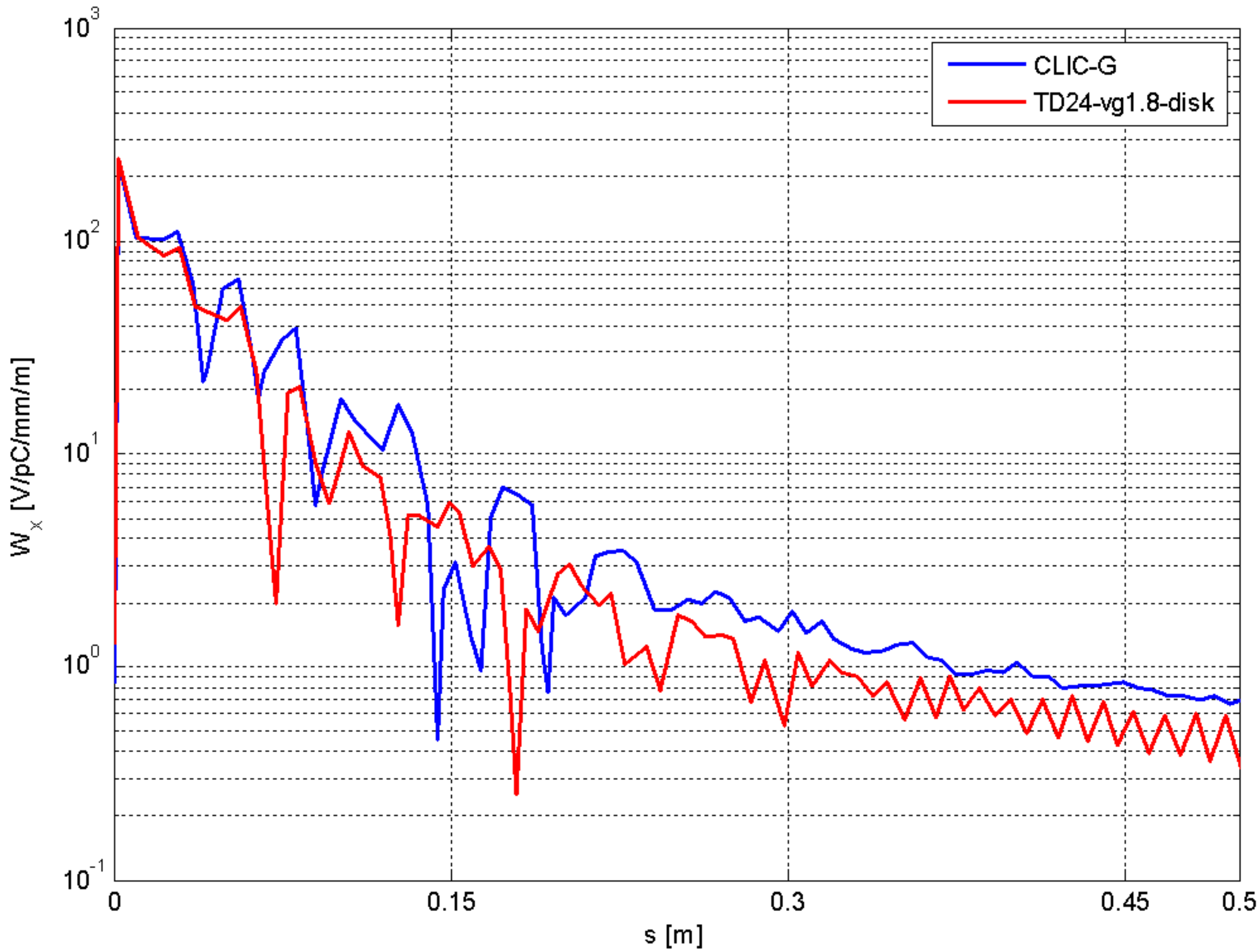
- Minimize E-field
- Minimize H-field
- Provide good HOM damping
- Provide good vacuum pumping

TD24_vg1.8_disk as CLIC_G proto

Currently available technology is Single rounded brazed disks



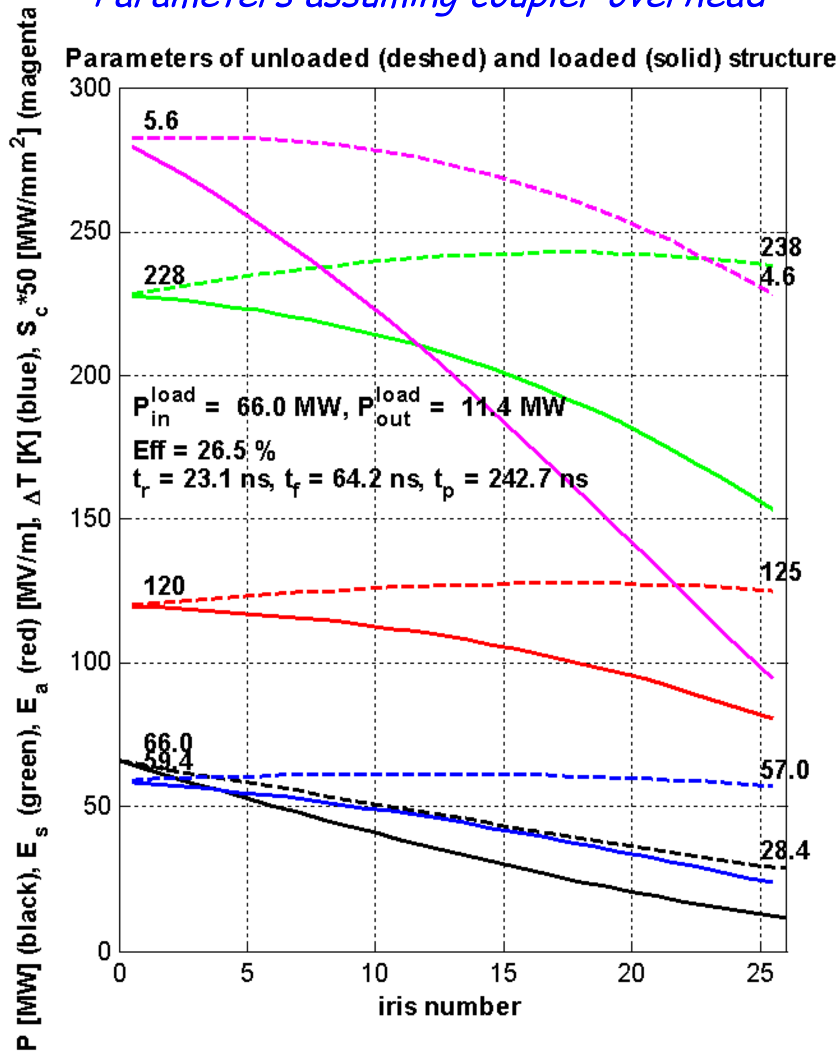
TD24_vg1.8_disk transverse wake



Parameters of TD24_vg1.8_disk

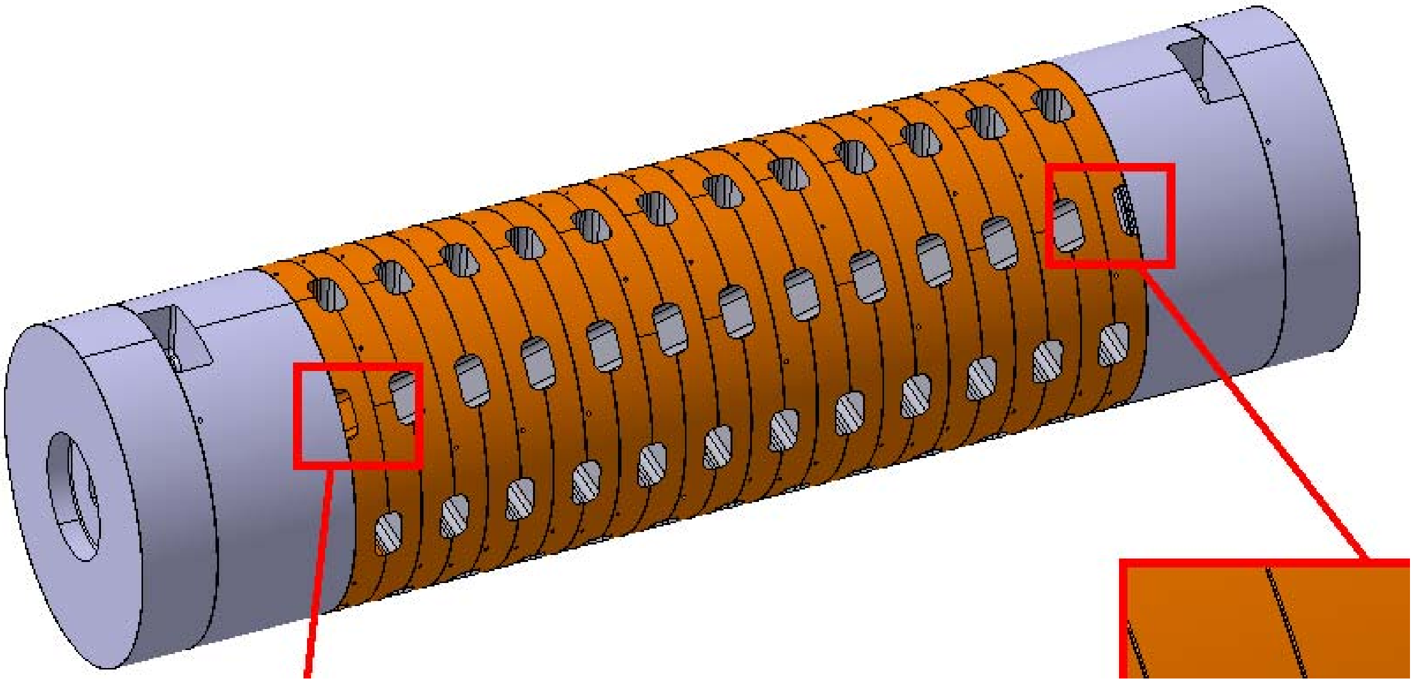
Structure	CLIC_G	TD24
Frequency: f [GHz]	12	12
Av. iris radius/wavelength: $<a>/\lambda$	0.11	0.11
In/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35	3.15, 2.35
In/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00	1.67, 1.00
Group velocity: $v_g^{(1,2)}/c$ [%]	1.66, 0.83	1.62, 0.81
N. of reg. cells, str. length: N_c, l [mm]	24, 229	24, 229
Bunch separation: N_s [rf cycles]	6	6
Lumi. per bunch X-ing: L_b [m^{-2}]	1.22 10^{34}	1.22 10^{34}
Bunch population: N	3.72 10^{9}	3.72 10^{9}
Number of bunches in a train: N_b	312	312
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4	64.2, 23.1
Pulse length: τ_p [ns]	240.8	242.7
Input power: P_{in} [MW]	63.8	66.0
$P_{in}/C t_p^{P\,1/3}$ [MW/mm ns$^{1/3}$]	18	18.6
S_c^{max} [MW/mm^2]	5.4	5.6
Max. surface field: E_{surf}^{max} [MV/m]	245	240
Max. temperature rise: ΔT^{max} [K]	53	62
Efficiency: η [%]	27.7	26.5
Figure of merit: $\eta L_b /N$ [a.u.]	9.1	8.7

Parameters assuming coupler overhead



Double rounded disk design

Double rounded disk design is under way



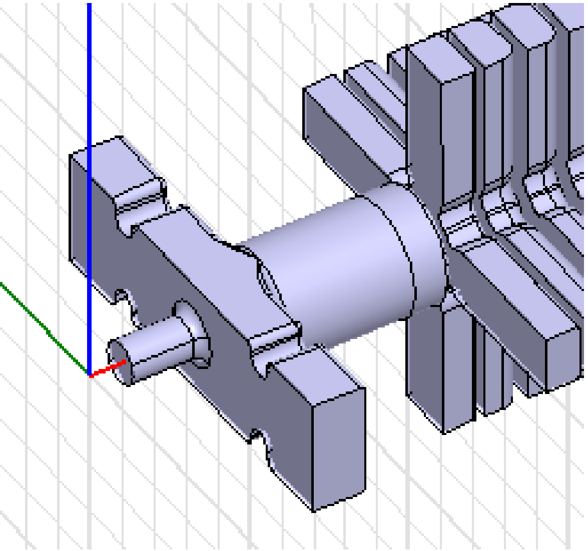
30'+ slides

Coupler alternatives

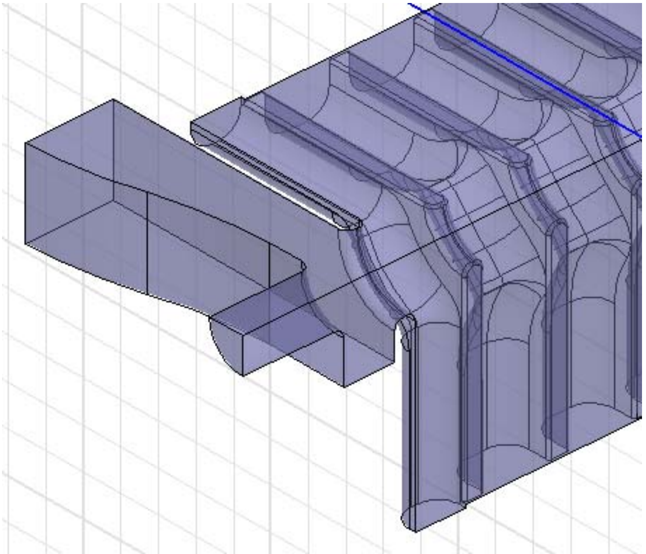
- Mode launcher coupler
- Electric coupler
- Magnetic coupler with damping

Coupler design

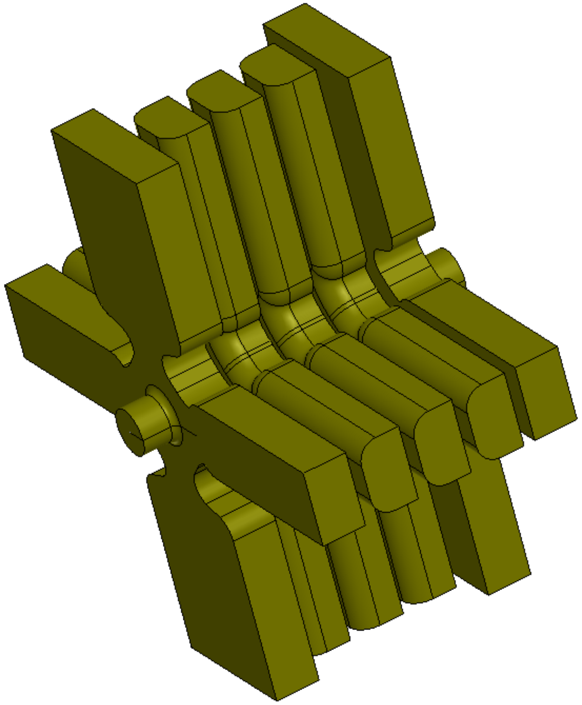
Mode launcher



Electric field coupler



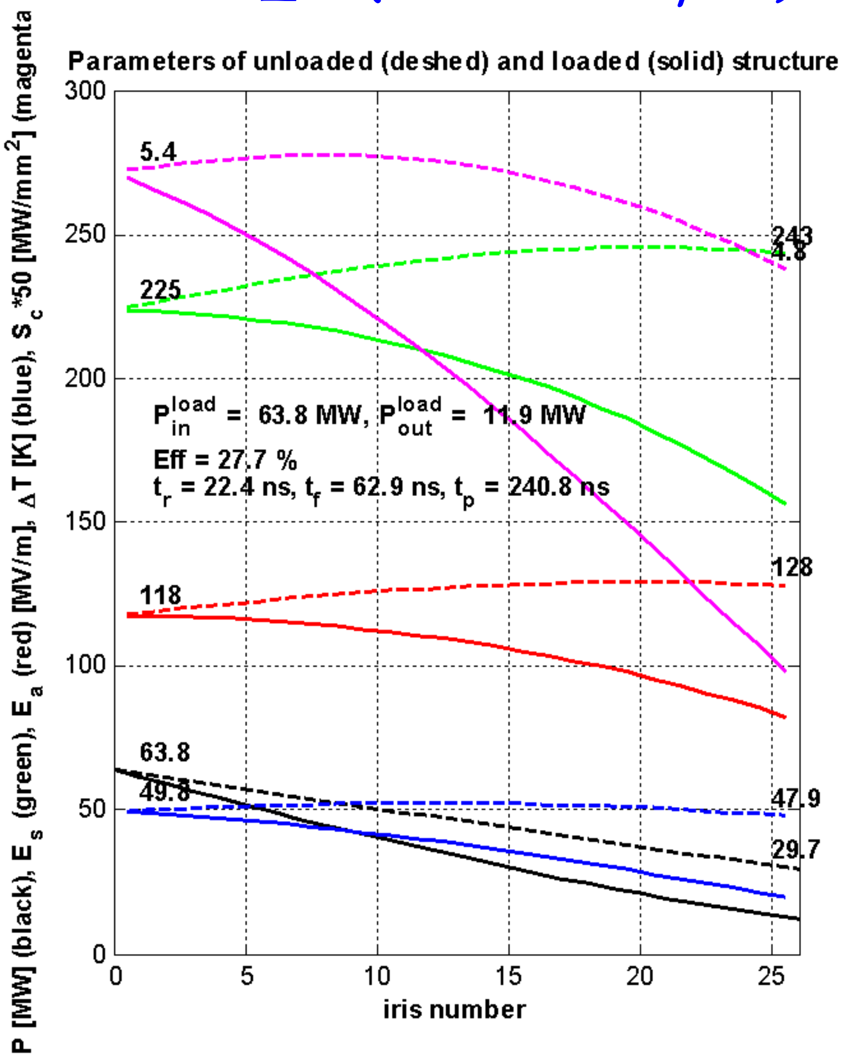
Magnetic field coupler



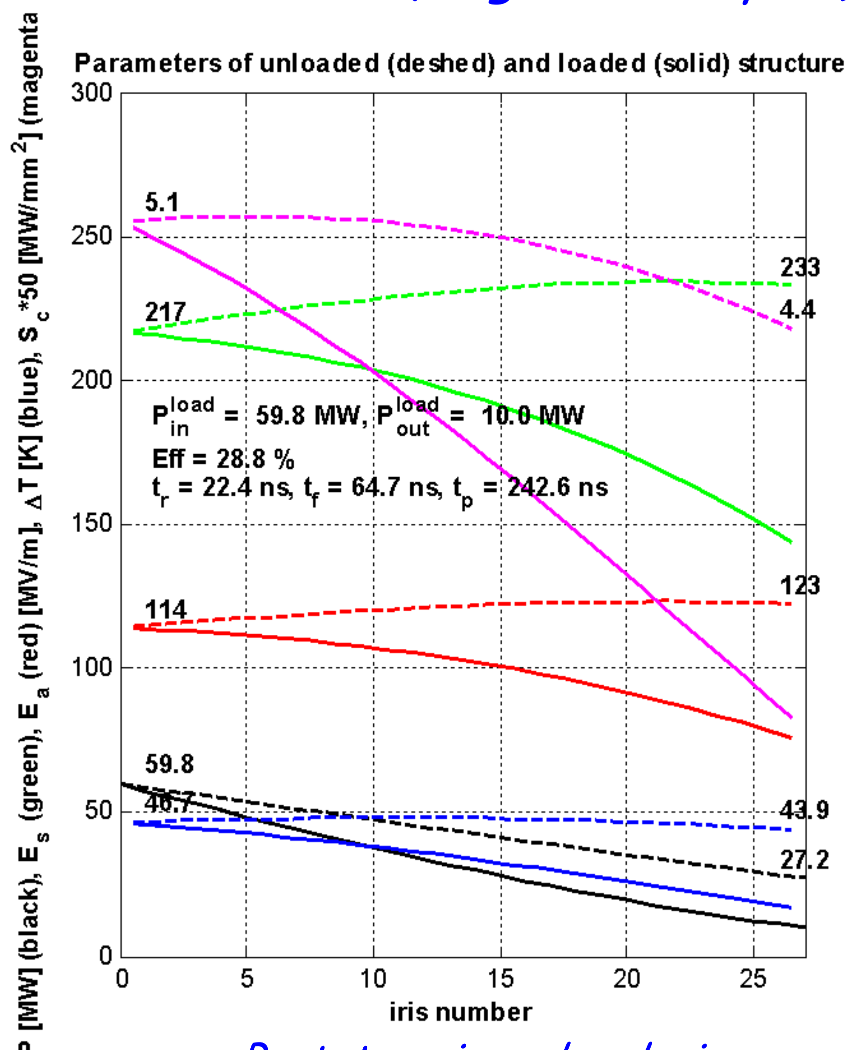
Compact coupler

CLIC_G + compact coupler

CLIC_G (electric coupler)



CLIC_GCC (magnetic coupler)



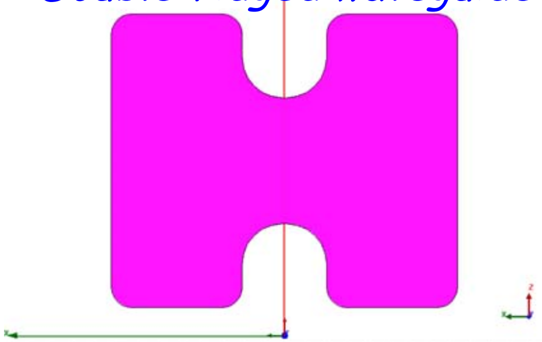
Prototype is under design

Ridged waveguide damping for lower pulse surface heating temperature rise

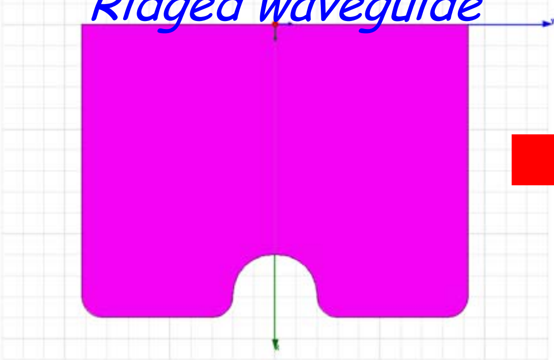
Ridged waveguide for HOM damping

Rectangular waveguide

Double-ridged waveguide



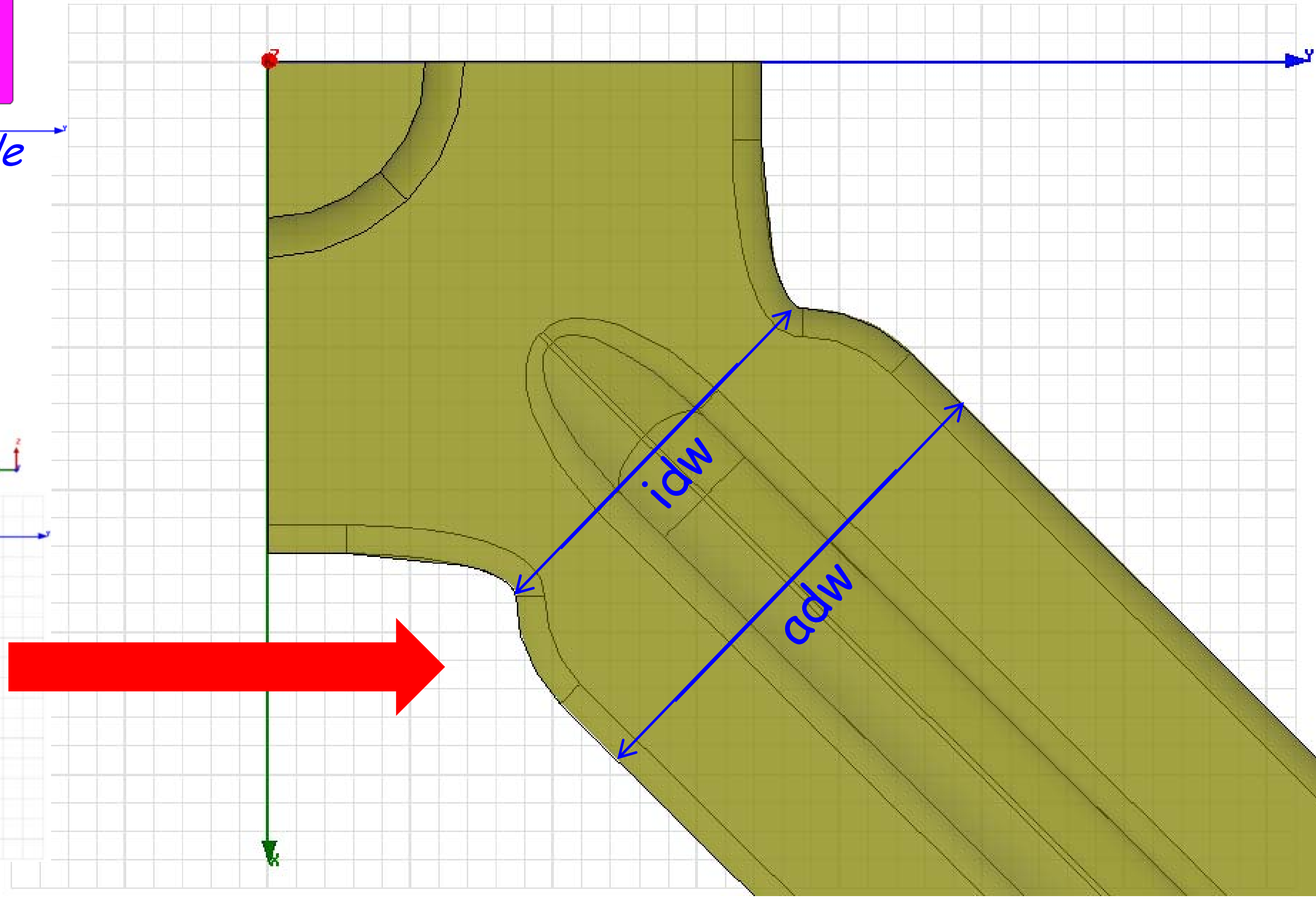
Ridged waveguide



CLIC_GLDT (low ΔT)

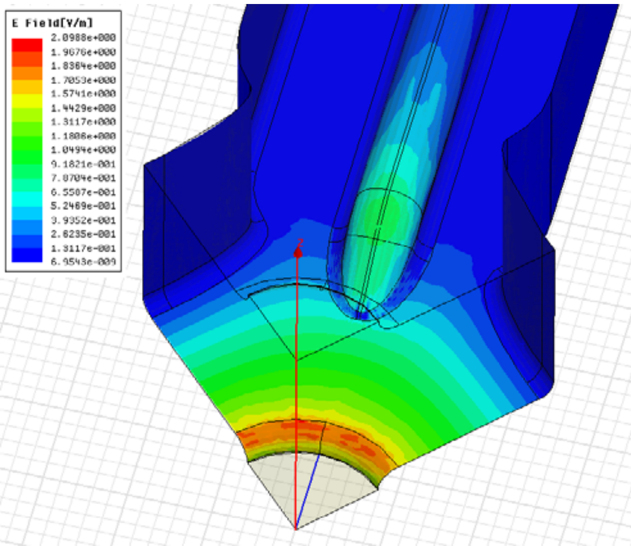
idw = 7.5 mm

adw = 9.25 mm

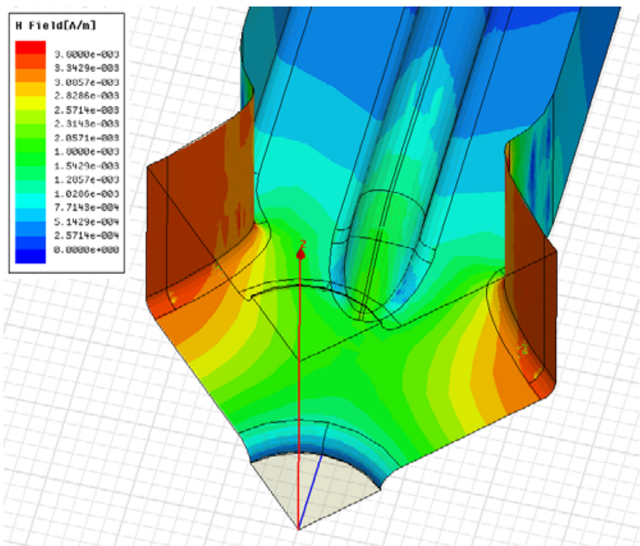


EM field configuration in RWDS

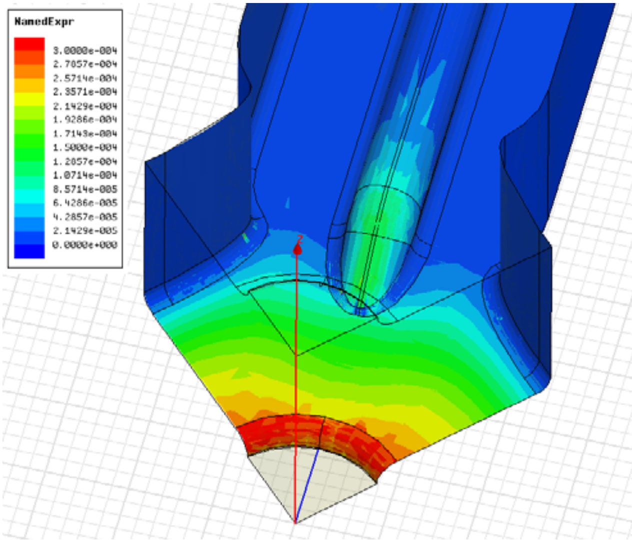
Electromagnetic field configuration on the surface of a Ridged waveguide damped structure (RWDS) cell



Electric field



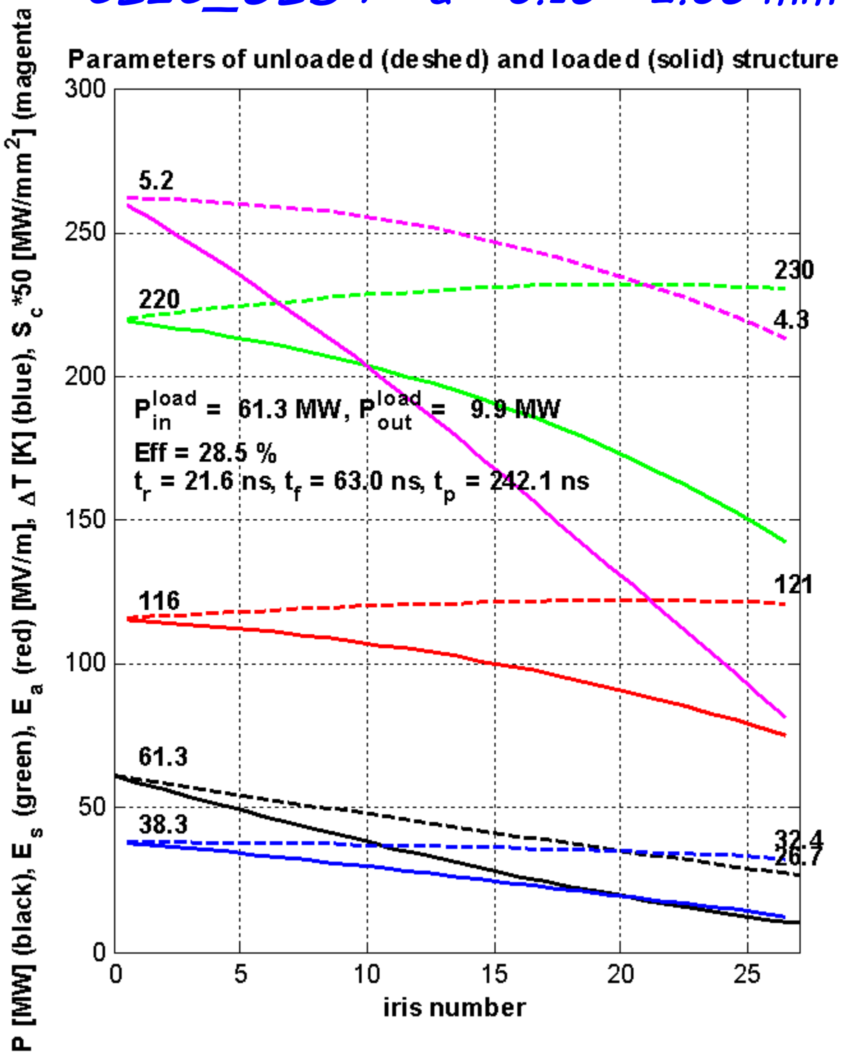
Magnetic field



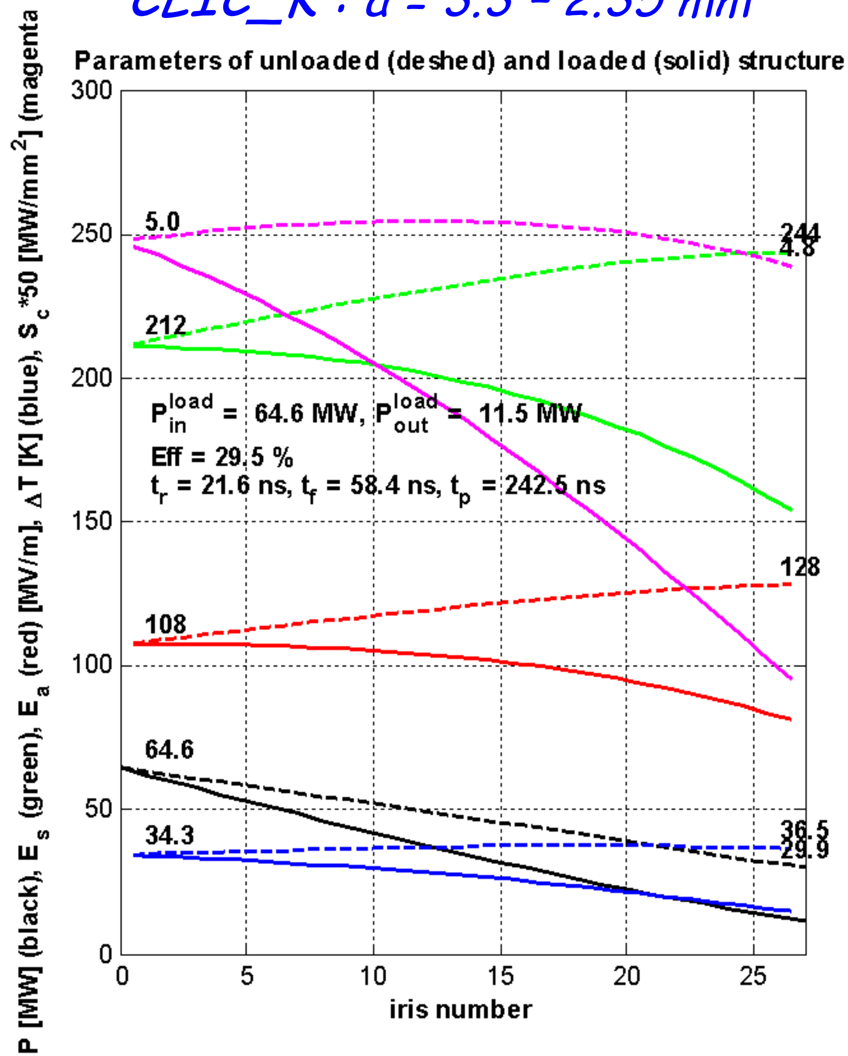
Sc

Structures with ridged waveguide damping

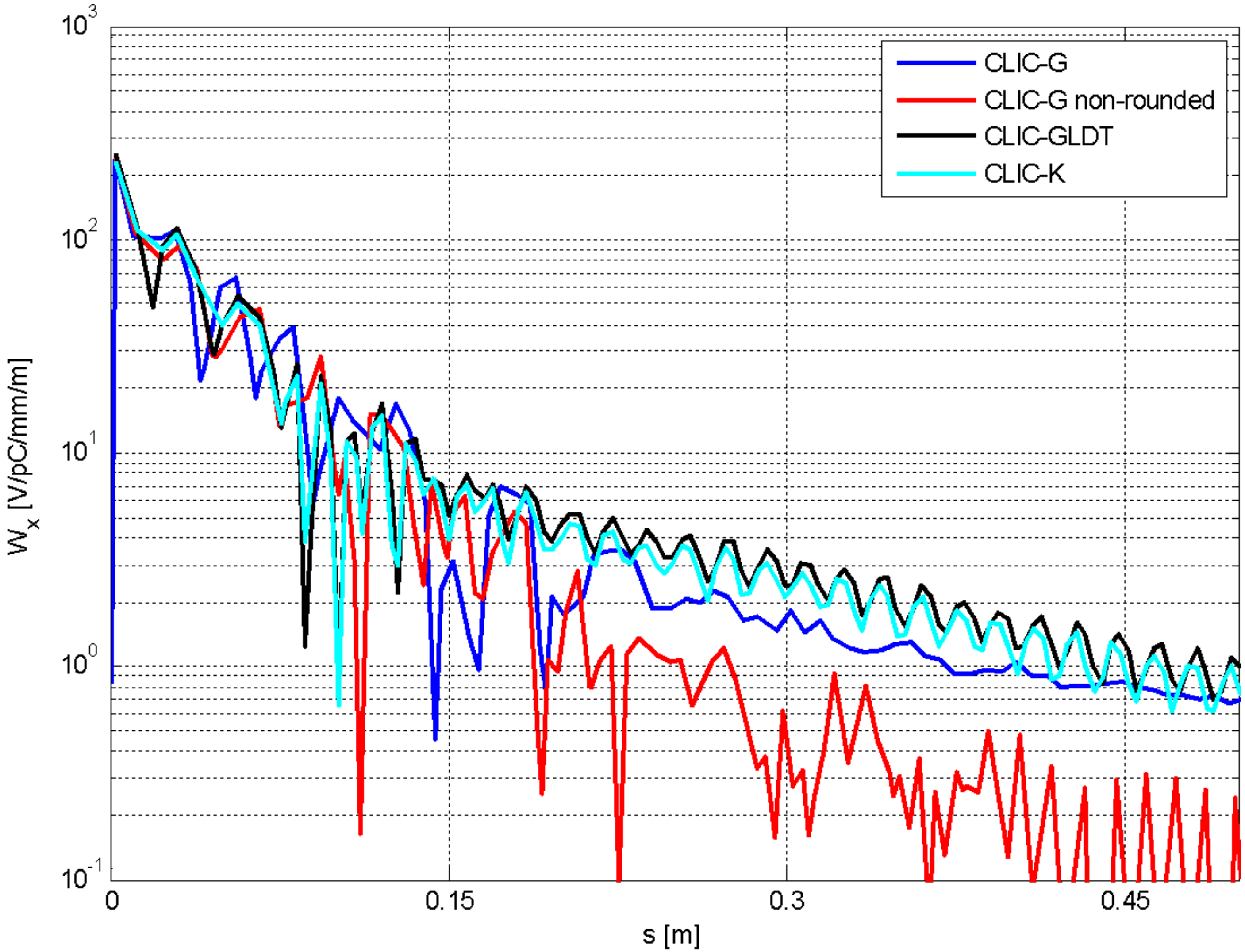
CLIC_GLDT : a = 3.15 - 2.35 mm



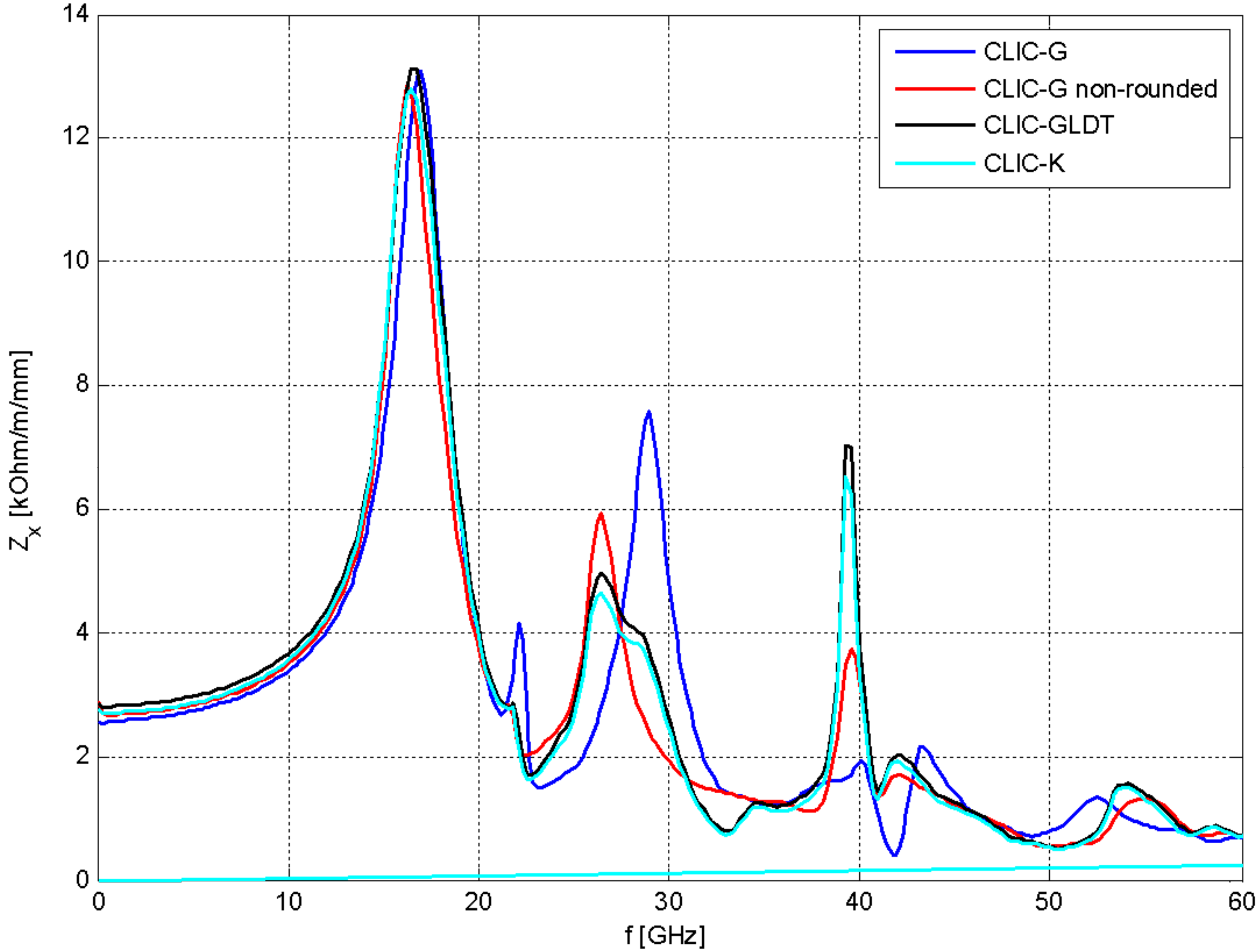
CLIC_K : a = 3.3 - 2.35 mm



Wake field of proposed structures



Transverse impedance



Parameters of the structures

Structure	CLIC_G	CLIC_GCC	CLIC_GCC non-rounded	CLIC_GLDT	CLIC_K
Frequency: f [GHz]	12	12	12	12	12
Average iris radius/wavelength: $<a>/\lambda$	0.11	0.11	0.11	0.11	0.113
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35	3.15, 2.35	3.15, 2.35	3.15, 2.35	3.3, 2.35
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00	1.67, 1.00	1.67, 1.00	1.67, 1.00	1.67, 1.00
Group velocity: $v_g^{(1,2)}/c$ [%]	1.66, 0.83	1.66, 0.83	1.67, 0.84	1.68, 0.86	1.97, 0.86
N. of reg. cells, str. length: N_c, l [mm]	24, 229	25, 225	25, 225	25, 225	25, 225
Bunch separation: N_s [rf cycles]	6	6	6	6	6
Luminosity per bunch X-ing: L_b [m^{-2}]	$1.22\ 10^{34}$	$1.22\ 10^{34}$	$1.22\ 10^{34}$	$1.22\ 10^{34}$	$1.28\ 10^{34}$
Bunch population: N	$3.72\ 10^{9}$	$3.72\ 10^{9}$	$3.72\ 10^{9}$	$3.72\ 10^{9}$	$3.94\ 10^{9}$
Number of bunches in a train: N_b	312	312	312	316	326
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4	64.7, 22.4	63.8, 22.0	63.0, 21.6	58.4, 21.6
Pulse length: τ_p [ns]	240.8	242.6	241.4	242.1	242.5
Input power: P_{in} [MW]	63.8	59.8	61.5	61.3	64.6 (65.2)
$P_{in}/Ct^{P}{}_{p}{}^{1/3}$ [$MW/mm\ ns^{1/3}$]	17.9	16.8	17.3	17.3	17.5
S_c^{max} [MW/mm^2]	5.4	5.1	5.3	5.2	5.1
Max. surface field: E_{surf}^{max} [MV/m]	245	233	230	230	244
Max. temperature rise: ΔT^{max} [K]	53	48	45	39	37
Efficiency: η [%]	27.7	28.8	28.1	28.5	29.5 (29.2)
Figure of merit: $\eta L_b /N$ [a.u.]	9.1	9.4	9.3	9.4	9.6

(95% of Cu conductivity)